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Near-infrared spectroscopy (NIRS) in functional research of prefrontal cortex

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Functional near-infrared spectroscopy (fNIRS) uses specific wavelengths of light to provide measures of cerebral oxygenated and deoxygenated hemoglobin that are correlated with the functional magnetic resonance imaging (fMRI) BOLD signal. fNIRS has emerged during the last decade as a promising non-invasive neuroimaging tool and has been used to monitor various types of brain activities during motor and cognitive tasks with increasing interest from research communities. One can see classical comprehensive reviews of such investigations elsewhere (Hoshi, 2003; Koizumi et al., 2003; Obrig and Villringer, 2003). While various MRI methods documented in the literatures have provided essential information about the brain systems concerning these issues up to the present, they have two major limitations, their requirement for participant immobility and their high operational cost. Particularly, the former rules out the use of such techniques for investigating brain dynamics during every activities such as walking and running. On the other hand, fNIRS can be used under less body constraints than other imaging modalities require. Moreover, it is quiet (no operating sound). Thus, the conditions for performing fNIRS measurements are much more comfortable for human as well as non-human subjects (Wakita et al., 2010). In addition, it provides higher temporal resolution (faster sampling frequency). In this respect, fNIRS is useful for studying brain activity under more “natural” and therefore much more variable conditions though it can only monitor cortical regions with less spatial resolution (usually in the centimeter range).

Since fNIRS is a non-invasive, safe and portable method, topics that NIRS researches could address are highly variable, and more diverse than those with other non-invasive imaging research techniques. That fact makes fNIRS an ideal candidate for monitoring activity of prefrontal cortex, which has been undertaken with respect to more broadly based issues across the broad expanse of research communities. In fact, many academic journals in diverse areas publish findings obtained from pioneering fNIRS measurements of prefrontal regions. We must admit that this diversity of fNIRS applications makes difficult to access accumulated experience. Protocols of fNIRS recordings from various investigations are not necessarily well-standardized and not necessarily well-grounded on available knowledge of appropriate fNIRS use. One of the purposes of the current research topic is to address this issue across both theoretical and empirical aspects.

In order to realize the high potential of fNIRS, effective discrimination between physiological noise originating from forehead skin hemodynamic and cerebral signals is a pre-requisite. Main sources of physiological noise are global and local blood flow regulation processes on multiple time scales. Having attempted to identify the main physiological noise contributions in fNIRS forehead signals and to develop a method for physiological de-noising of fNIRS data, Kirilina et al. (2013) documents a set of physiological regressors, which are used for physiological de-noising of fNIRS signals. New imaging methods to fuse fNIRS measurements and fMRI data are presented

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to reveal the spatiotemporal dynamics of the hemodynamic responses with high spatiotemporal resolution across the brain (Yuan and Ye, 2013). Recognition algorithm is described for recognition whether one taps the left hand or the right hand (Hai et al., 2013). In the study, data with noises and artifacts collected from a multi-channel system is pre-processed using a Savitzky-Golay filter for getting more smooth data. These results are confirmed by another study (Wakita, 2014).

A more ambitious and challenging attempt is set out by two groups of scientists independently from each other, but in a similar manner, to explore the possibility that fNIRS can serve as a replacement of fMRI in clinical settings. In order to examine whether fNIRS is equipped with necessary sensitivity as a potential alternative of fMRI, they investigate the sensitivity to detecting linear changes in activation and functional connectivity in response to cognitive load, and functional connectivity changes when transitioning from a task-free resting state to a task performance (a letter n-back task with three load conditions). The results demonstrate that fNIRS is sensitive to both cognitive load and state (Herff et al., 2014). Interesting, almost identical findings are reported by another group of scientists (Fishburn et al., 2014). These findings strongly indicate the fNIRS-measured prefrontal activity to discriminate cognitive states in real life. Arguments that support this conclusion as well as suggestive evidence for the claim are presented (Derosiere et al., 2013; Harivel et al., 2013; Yoshino et al., 2013a,b).

The most intensively investigated issue in the functional research of prefrontal cortex is that concerning working memory, particularly executive function. It is not surprising therefore that several articles deal with the issue in the current research topic. A review (Moriguchi and Hiraki, 2013) summarizes quite concisely recent advancements by fNIRS research on the development of executive function in children. It particularly concentrates on the lateral prefrontal cortex, focusing on inhibitory control and cognitive shifting. The remaining four research articles deal with divergent issues, e.g., music (Ferreri et al., 2013), story-telling (Moro et al., 2013), the Scarborough adaptation of the Tower of London (Ruocco et al., 2014), and gambling (Bembich et al., 2014). While actual issues addressed in the studies are variable, they commonly deal with encoding and decoding processed of memories stored in the working memory system for our daily activities. This diversity of topics addresses multifaceted aspects of applying NIRS to various scientific disciplines such as pediatrics, psychology, psychiatry, neurophysiology.

Another research direction addresses emotional influences on prefrontal activity, the number of reports in this area has been increasing. In particular, processing emotional visual stimuli to produce these effects is drawing attention. An article (Doi et al., 2013) reviews unique characteristics of fNIRS as an effective tool for investigating the role of the prefrontal cortex in emotional processing. Admitting several obstacles in the application of fNIRS to emotion research, they discuss the implications of recent findings to assess the effects of prefrontal activation on emotion, specifically addressing the methodological challenges of NIRS measurements with respect to the area of emotion research. They discuss potentials of the two research fields for investigating (i) biological pre-dispositions influencing prefrontal responses to emotional stimuli and (ii) neural mechanisms underlying the bi-directional interaction between emotion and action, have much to gain from the use of fNIRS. The latter issue is also addressed by another group of scientists (Sato et al., 2014), who reports that the mood-cognition interaction occurs in the lateral prefrontal cortex, a brain region known to associate with the executive function of the working memory system closely (Moriguchi and Hiraki, 2013). Other two studies concentrate on recordings in the activation of medial prefrontal cortex when viewing visual images (non-art pictures or art pieces). In both studies, some modulation of the brain activation is confirmed. However, it is more robust when presenting art pieces (Kreplin and Fairclough, 2013) than non-art pictures (Ozawa et al., 2014). Among such art pieces, the activation was more robust when the presented images were evaluated as more esthetic than when they were evaluated as less esthetic. Based on the findings, the authors of the article conclude the activated brain region is involved during positive evaluation of visual art that may be related to judgment of pleasantness or attraction.

In summary, this research topic has provided a forum for scientists planning functional studies of prefrontal brain activation using fNIRS. We hope this will serve as a reference repository of knowledge from these fields as well as a conduit of information from leading researchers. In addition it offers an extensive cross-referencing system that will facilitate search and retrieval of information about NIRS measurements in activation studies. Researchers interested in fNIRS would benefit from an overview about its potential utilities for future research directions.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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